Enhancing Productivity through simulation and layout planning: A Case Study of a Manufacturing company in South Africa.

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Abstract (12 font)

This paper aims to optimize a manufacturing process through creation of a simulation model that will be used to identify bottlenecks, restructure the layout and improve productivity. The paper also highlights the significance of process optimization in a manufacturing set up. Process optimizations strive to find the best solution for a process within the available constraints. Simulation is a collection of methodologies used to mimic the characteristics and behaviour of real system using computer software. Literature review was carried out to understand system dynamics and simulation. A case study was conducted at a manufacturing company. An Arena simulation model representing the process under study was developed and analysed. Various models were run and the results compared. The best model was developed that improved productivity through restructuring of the layout and minimization of the cycle times on the identified bottleneck stations. The simulation results showed that there was a vast difference on the amount of material input and the ATMs and Safes produced. The limitation of this study was that it only focused on the production of two products in the case studied company.

Keyswords: Optimization, Simulation, modelling, Bottleneck and Productivity

1. Introduction

Manufacturing is an economic vehicle that improves the living conditions of any country's population through creation of employment, provision of goods and services, and its support to the country's Gross Domestic Product (GDP), (Chryssolouris, 2006). Manufacturing is a transformation process of converting raw material or data into a tangible product or service that is within customer specifications, Robinson, (1993). Customers are always looking for unique products and services at affordable prices and within short lead times, Robinson, (1993). This places pressure on manufacturing industries to perform and maintain their competitive edge. Increased globalization and decentralisation of manufacturing industries, including pressure to satisfy the ever-changing demands of customers are some of the attributes that drives companies to seek improvements of their processes, Moutzis and Doukas, (2008). Manufacturing managers are always encouraged to increase throughput, reduce unnecessary inventory and improve quality, Robinson, (1993). Hence cost reduction and efficiency improvements are some of the common factors that manufacturing companies focus on in-order to remain profitable, Chryssolouris, 2006). However the choice of an appropriate process, equipment, organization and operational control remains a challenge in many manufacturing industries. Productive manufacturing companies employ both analytical and engineering strategies to remain competitive in the market. This study looks at optimising a manufacturing process of a local company through simulation modelling.

Computer simulation has been used as a tool to develop manufacturing solutions and as an aid in decision making since the 1950s, Robinson, (1993). Simulation modelling imitates reality, in this study the model will imitate the operations of machines, the movement of workers and work in progress, utilisation of labour and quality levels. In this paper, Arena software was used to develop and simulate the manufacturing of safes. Various experiments were performed by running the model for a simulated time period. Different data were tested by changing the inputs to the model and through a reconfigured layout. The studied company will be known as Company A in this paper.

1.1 Research Objectives

This paper make use of discrete-event simulation in a case study research with twofold objectives:

- To investigate bottleneck stations in a safe production line and
- To increase throughput through installing buffer stations.

1.2 Research Questions

- To what extent does a simulation model assist in enhancing productivity and optimization for a manufacturing production line?
- What impact do facilities layout changes have on productivity?

2. Literature Review

2.1 Simulation in Manufacturing Environment

There are several modelling and simulating software in the market that are used for scheduling, forecasting, testing and analysing manufacturing systems, (Anand and Kodali, 2009). Law, (2007), suggested that, "manufacturing systems are dynamic and stochastic systems, hence they generally use discrete-event simulation". A study by El-Khalil, (2009), established that, "most manufacturing companies use discrete computer modelling and simulation to design, analyse behaviour, predict performance, and recommend systems changes, study labour and machine changes on throughput within manufacturing processes". Several authors agree that discrete-event simulation can be used to solve a number of challenges in a manufacturing set-up such as, (Law, 2007; Santos et al, 2012; Sandhu et al, 2013 and El-Khalil, 2015):

- "evaluation and verification of new proposed processes,
- determining resource requirements for example machines, robots, labour, pallets and buffer size,
- determining the optimal size of buffers,
- performing different types of analysis for issues such as throughput, time-in-system, bottleneck, sensitivity, reliability, maintenance, time to repair and time between failures".

Kumar and Phrommathed, (2006), used simulation software, ARENA, to solve efficiency problems in a paper manufacturing facility. They implemented several lean tools and their study improved annual cost by $450 000. El-Khalil, (2013), used the Witness simulation in an axle manufacturing facility to identify bottleneck and critical stations. Soon and Souzar, (1997), solved scheduling problems in a manufacturing facility through a hybrid approach that used simulation and neural network. Agarwal and Babu, (1994), used a simulation support to study Material Requirements Planning (MRP), based production system through variation effects in Master Production Schedule (MPS), Bill of Materials (BOM), capacity planning, inventory supports and lot sizing. Wu et al, (1994), analysed a new manufacturing approach that included the Drum-Buffer-Rope (DBR). Their simulation results indicated that some savings were achieved when DBR replaced the conventional control approach. El-Khalil, (2015) reported that a study conducted at General Motors, truck manufacturing plant, used Siml8 and implemented a Flexible Manufacturing System (FMS), for buffer and rework stations and reduced cost by $1.1 million annually.

The simulation software used in this study, (ARENA), allows the developer to create a model that resembles the real manufacturing plant processes. As a decision support tool, simulation enables different scenarios to be tested on a trial-and-error basis. A preliminary simulation model grants the opportunity to explore the complexity of a real situation, with the aid of software (ARENA), (Pedgen et al, 1995). This software has powerful features and tools, which grant the end user to develop, test and analyse current and new operation. This gives the end user the privilege to create model up to the expectation of real situation (manufacturing), a premature conclusion can derived before the actual system is fully implemented, (Pedgen et al, 1995; Hlupic, 1999).

Robinson, (1993), summarised questions that can be asked by a model developer as:

- What effect will faster cycle times have on throughput?
- Will fewer maintenance teams significantly increase machine stoppages?
- What if buffer storage is increased by 10 per cent?
- What effect will changing the layout have on labour efficiency?

Discrete event Simulation (DES), (Kelton et al, 2015), was used in this research paper, to analyse process, layout and resources changes required to enhance efficiency in a safe manufacturing company in South Africa. Discrete event simulation (DES), was selected for this research paper. DES is a process of arranging the actions of complex system in an ordered and sequentially well-defined events. Events are made up of specific changes in the system's state at definite point in time, (Hlupic, 1999). DES is used in many analysis such as assessing financial investments like the stock market and modelling procedures in manufacturing and service industries. A potential DES process must include the following characteristics, (Kelton et al, 2015):

- "Predetermined starting and ending points, which can be discrete events or instants in time;
- A way of keeping track of the time that has elapsed since the process started;
- A list of discrete events that have occurred since the process begun;
- A list of discrete events pending or expected until the process is expected to end and
- A graphical, statistical or tabular record of the function for which DES is presently engaged".

Buffers are used in a production or assembly line to avoid losses caused by either waiting for material or managing a bottleneck station, Slack et al., (2014). However adding buffer storage requires proper planning because it involves more capital expenditure such as floor space on the production line and cost of inventory. The overall benefit of a buffer storage takes into account buffer space cost and the cost of holding inventory. In manufacturing operations buffer storage separates materials handling and production operations, Malmborg, (1995), and it improves effective use of both equipment, manpower, machine reliability, scheduling and throughput. Buffer storage systems are normally used in manufacturing operations where the variation for product is high and production volumes that are low, Slack et al, (2014).

The authors created a simulation model that progresses (queuing systems) through time. Queuing systems permits editing and modification of each process during the simulation modelling exercise. Queuing systems can be found in fast food, manufacturing companies and banks among other system entities, Law and Kelton, (1991). Material flow and production flow time are one of the factors to be taken into consideration during the simulation modelling exercise. These parameters can be compared in two different scenarios and facilities, Banu and Arslan, (2011). Simulation models provides a platform for end-to-end analysis and can be used to modify complex production systems, Kim and Choi, (2014).

2.2 Lean Manufacturing-7 Types of waste

The concept of lean manufacturing dates back to the days of the late Henry Ford .This concept is based on the principles (Toyota Production Systems) of doing more work with less resources. Waste elimination is the primary goal for this concept, (Acaccia et al, 1999). Lean Manufacturing Tools, (2016) stated that there are seven types of waste according to lean manufacturing: "waste of transport, waste of inventory , waste of motion ,waste of waiting ,waste of over production ,waste of over processing and waste of defects". (Law and Kelton, 1991). Company A is a safe manufacturing in South Africa, which produces products and services that are based on customization.

Adoption of this principle (Lean Manufacturing) requires changes in facilities, material flow and work ethics, (Lean Manufacturing Tools, 2016). Figure 1 shows the various forms of waste.
The non-value adding activity of transport (movement) is described as, “the movement of material from one location to another, that is not directly associated with a value adding process. Financially the waste is due to the cost of the material handling equipment, staff to operate it, safety precautions and training”, (Lean Manufacturing Tools, 2016).
Inventory waste is made up of materials that is yet to be processed, work in process stock and finished goods that are held in excess of what is required to produce the finished product to meet customer demand. Costs associated with inventory are the material itself, transportation, storing, including: “administration, warehouse staff, damages and the cost of writing off obsolete materials”, (Lean Manufacturing Tools, 2016).

Figure 1. 7 Types of waste, (Lean Manufacturing Tools, 2016).

Any motion from man or machines that is non-vale adding is regarded as a waste. The waste of motion affects worker efficiency due to non-value adding activities such as spending more time in lifting, retrieving and looking for parts than actually machining, welding or assembling. The non-value addition activity of motion is caused by poor workstation arrangement, the placement of tools, equipment, non-assembled parts and worker body position, (Lean Manufacturing Tools, 2016).
The waste of waiting is generated by two independent processes that are not synchronised. Normally the waste of waiting is caused by lack of information, overproduction, inventory, transportation and processes. This waste is removed by balancing production processes, reducing overproduction and inventory and implementing standard operating procedures, (Lean Manufacturing Tools, 2016).
Poor (over) processes is a waste caused by adding more into a product than what the customer really want, like unnecessary close-fitting tolerances and adding excessive complexity to parts. This waste is removed by reviewing product designs and processes that are non-value adding, (Lean Manufacturing Tools, 2016).
Over production is considered as the worst of all the 7 wastes. It is caused by producing more than what is required by the customer at a specific point in time. Over producing results in a company tying up its capital in raw materials, stock, work in process and finished goods. This waste is solved by building trust with suppliers so that they deliver on time and by improving company processes such as production planning and forecasting, (Lean Manufacturing Tools, 2016).
Defects are caused by manufactured parts that do not meet customer requirements or specifications. Defects are associated with costs such as those found in problem solving, waiting time, material, rework, transport, rescheduling materials and paperwork. This waste is removed by improving standard operating procedures, training teams to come-up with solutions and prevent their own problems, (Lean Manufacturing Tools, 2016).

2.3 Queuing Theory

Kelton et al, (2015) stated that, “queuing theory is an operational research tool, used to manage waiting lines/ queues by providing insight into the queue and waiting times”. The queuing theory is incorporated into the Arena simulation software, (Kelton et al, 2015). Queuing theory helps to solve problems related to scheduling, waiting times and network performance. Queuing problems are quite common in manufacturing lines and are also present in the current study.

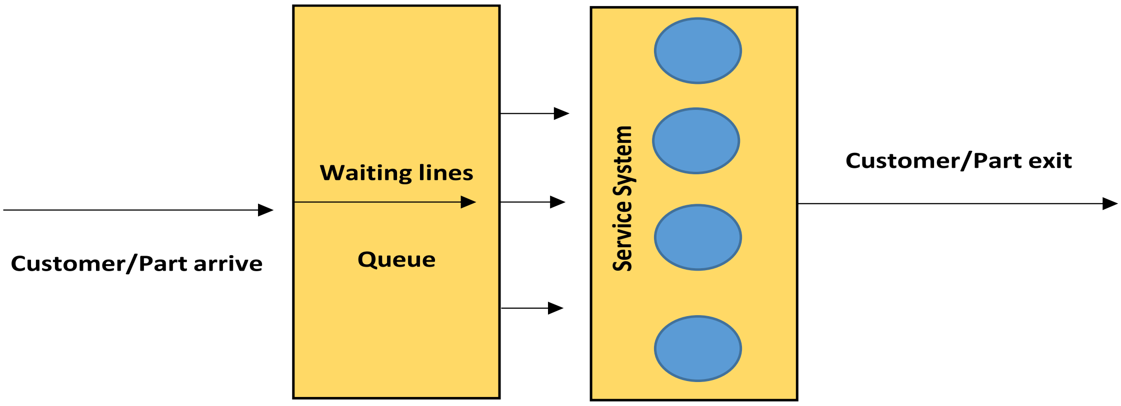

Figure 2, Diagrammatic View of a Queuing Process, (Kelton et al, 2015).

2.4 Adjustable variables in manufacturing to achieve performance

Carson and Maria, (1997), presented a model shown in Figure 3 that shows inputs, process and outputs variables that are commonly found in a manufacturing set-up. Some of the inputs and outputs shown below are found in the manufacturing of the safe under study. Simulation model are made up of n inputs variables (x_1, x_2,…,x_n) and m output variables (y_1, y_2,…,y_m). Inputs can be varied to obtain an optimum output.

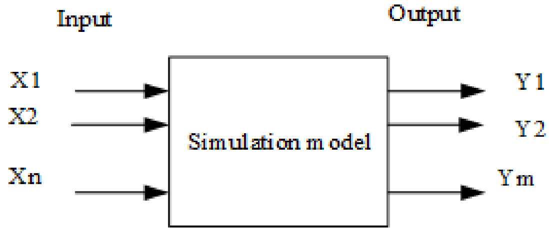

Figure 3. A Simulation Model, Carson and Maria, (1997).

3. Methodology

The safe production line is an ever-changing system which can experiences changes arbitrarily or as time changes. Discrete event simulation is a tool that can be used to evaluate and improve complicated systems such as the safe production line, Sandhu et al, (2013). Santos et al, (2013), proposed that dynamic and stochastic behaviours of a process can be analysed through discrete-event simulation. Sandhu et al, (2013), further concurred that, “discrete-event simulation is a useful cost-effective tool used for designing, analysing and optimising manufacturing processes”. The method adopted for this study is discrete-event simulation and it is a methodology that is oftenly used in most simulation work, (Law, 2007; Sandhu, 2013). An initial model will be created as a base-case model and then an improved model will incorporate changes that will enhance productivity of the safe production.
The researchers identified the following problems in the safe production line:

- Uncoordinated production activities,
- Late delivery and long waiting times,
- Frequent breakdowns and too long changeover times and
- Low production throughput.

Figure 4, shows research main and partial objectives of this study and the measures that will be undertaken to fulfil the objectives.

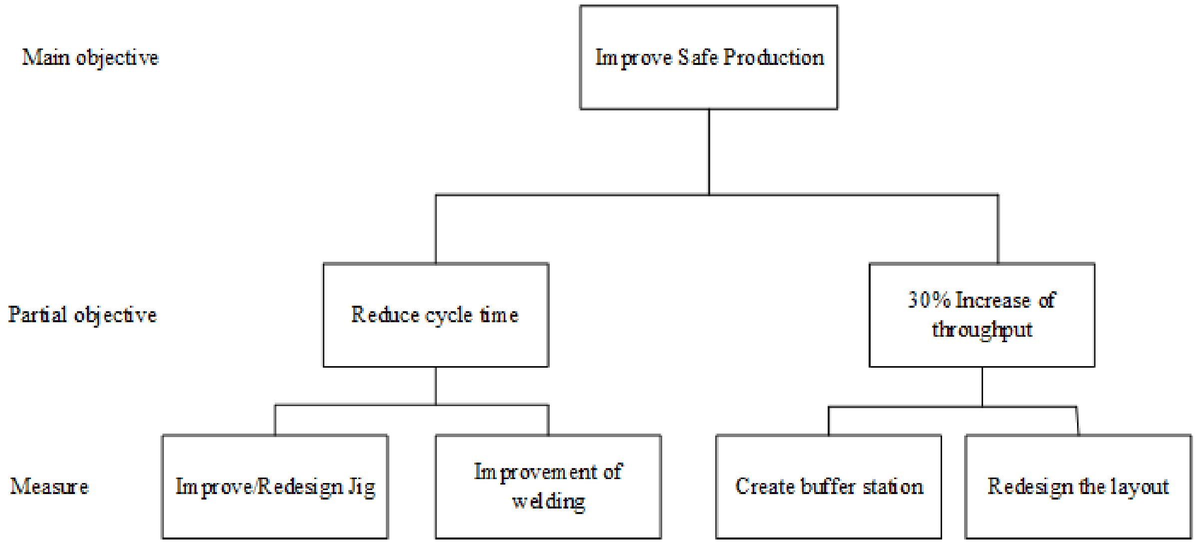

Figure 4. Research main objectives, (Own creation).

3.1 Model design stages

Four stages were followed in studying, developing and analysing the current production line:

Step 1: Process mapping

The safe manufacturing line process map was developed. Figure 4, shows all the steps that are followed in manufacturing a safe. The current layout is shown in Appendix 1. The scope of interest in this study focused on the production of a safe. Motion, movement (transport) and waiting were the type of waste identified, which have a major influence on the productivity of the simulation model. There was no buffer station for the welding operator; hence motion and waiting were identified as some of the waste elements. Parts were being delivered on the shop floor by a fork lift driver after each hour.

Step 2: Data collection and resource utilisation analysis

Actual data pertaining to safe fabrication was collected from the production planning department including observations and time studies on the shop floor. This data was then analysed and used for simulating the initial model.

Step 3: Redesign process

A new layout that included buffer storage was designed. New operational cycle times were then estimated from the new layout and were used in simulating an improved model. After the bottleneck was identified, management proposed that the researchers incorporate a buffer station close to the welding station in-order to reduce waiting times, unnecessary movement and motion. Management came up with the buffer and batch size. Other variables such as labour, maintenance downtime and repair times were not considered in this model.

Step 4: Implementation and evaluation

Various scenarios that included use of the buffer were tested using the simulation model. Improvements on labour utilisation, reduction in cycle times, increased output were achieved.

3.2 Current Process Flow

Material and Production flow are key elements to any production system. Figure 4 display the flow process chart of safe starting with welding operation until the product reaches the warehouse.

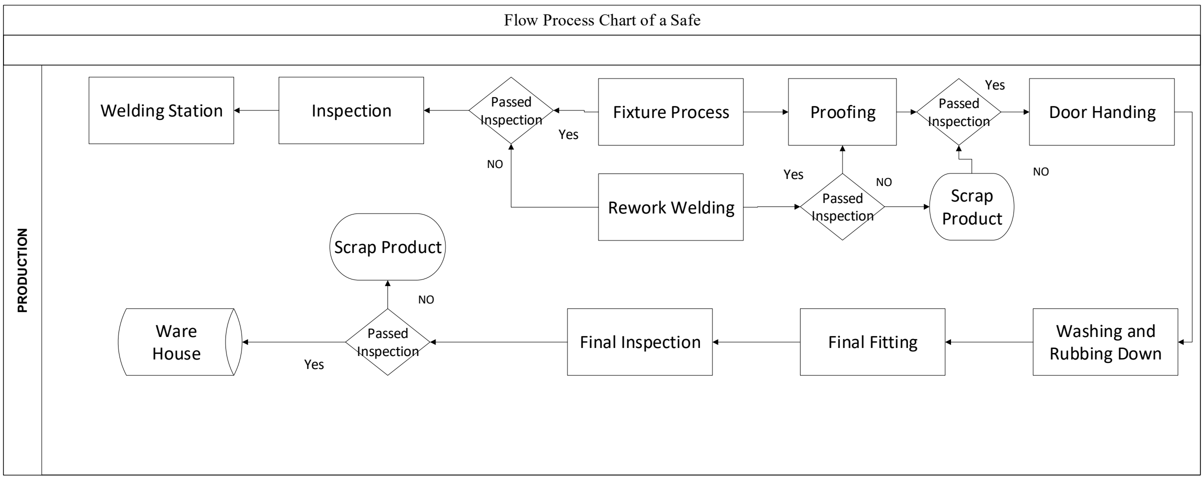

Figure 4: Flow Process chart of a safe production.

4. Model Development

4.1 Simulation Model and its elements

The simulation model in the safe production line was developed through the software ARENA. The researchers used modelling modules from the basic, advanced and advanced transfer. Figure 5 to Figure 8, illustrates the Arena simulation Model of a safe product. This research paper focuses on optimizing a safe manufacturing process. The process starts with welding in figure 5, followed by inspection and fixture process in Figure 6.After inspection is conducted all the confirming products proceed to fixture process and the non –confirming products are send to the rework station (includes the fixtures). Products which fail inspection after rework are scraped. All the confirming products proceed to proofing process, where refine concrete is placed inside the safe and left for 24 hours to cure. Products which are non-conforming after proofing are scraped and the conforming proceed to door hanging and washing and Rubbing down, Figure 7. Figure 8 shows final fitting, final inspection and warehouse.

The model was created based on the following assumptions:

- The production line operates 8 hours a day on 3 shifts, 5 days per week;
- Replication parameters are based on production hours;
- There is no frequent break down or machine set up times;
- Material Handling (Fork lift) are formed part of the resources instead of process e.g. Transport.

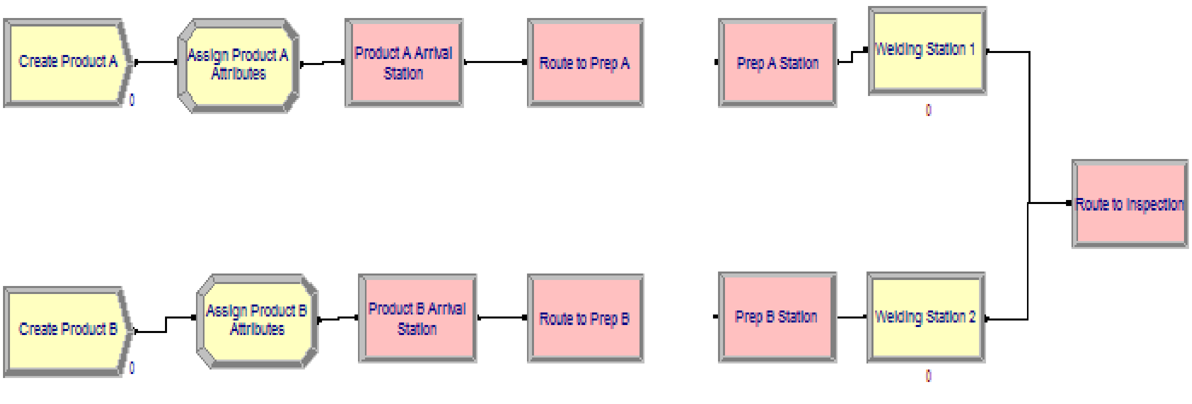

Figure 5: Sub Model Welding Process

To enhance understanding the model was segmented into four sections namely welding process ,inspection ,door hanging & washing and final fitting ,final inspection and warehouse. It is important to note that all the models formed one model which was simulated and analysed.

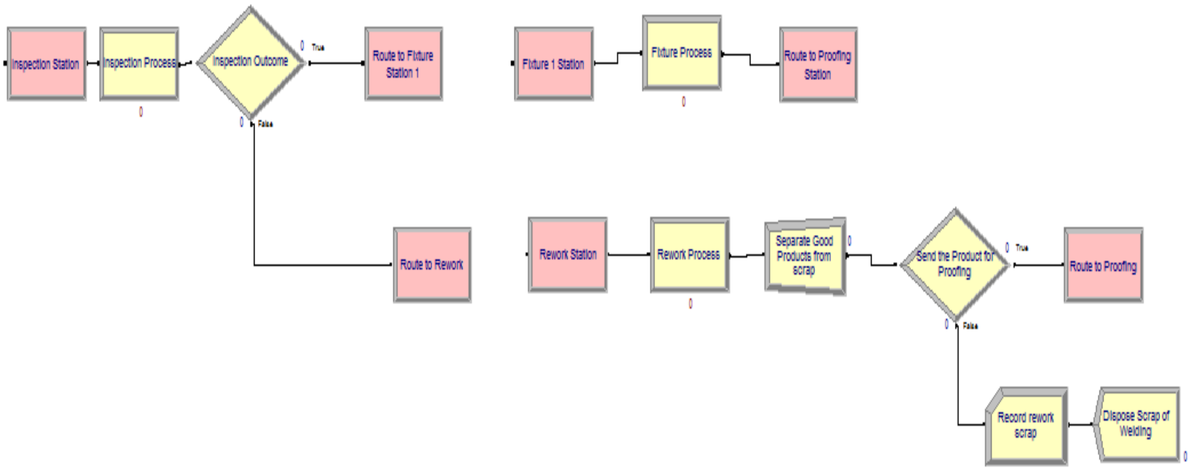

Figure 6: Sub Model Inspection and Fixture process

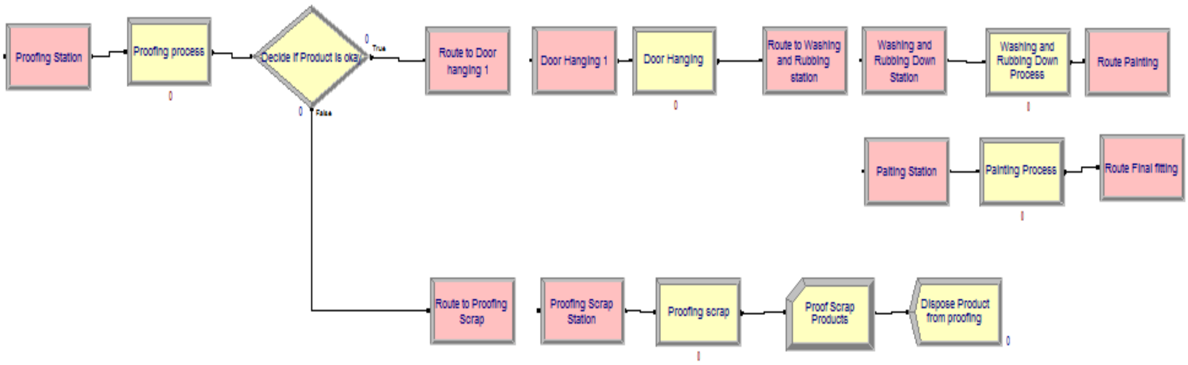

Figure 7: Sub Model Proofing, Door hanging, washing and Rubbing down process

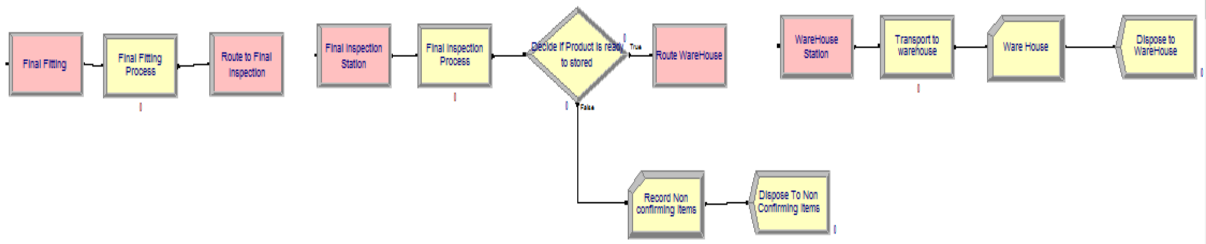

Figure 8: Sub Model Final Fitting, Final Inspection and warehouse.

4.2 Process Times

All the process distribution functions and Expression can be found in Table 1:
Input for product A is Random Expo (47) minutes
Input for product B is Random Expo (30) minutes
Replication Length is 7200 minutes (3 shifts of 8 hours in 5 days)
The proposed new model has a new layout and buffer stations that reduces motion, movement and waiting at the welding station.

Table 1: Distribution Functions

Process	Current Model	Proposed Model
	Expression Time(min)	Expression Time(min)
Welding Station 1	TRIAL(4,7,10)	TRIAL(3,5,6)
Welding Station 2	TRIAL(3,5,10)	TRIAL(2,5,7)
Inspection	EXPO(10)	EXPO(10)
Fixture Process	TRIAL(4,7,11)	TRIAL(4,7,11)
Rework Process	TRIAL(14,25,50)	TRIAL(14,25,50)
Proofing Process	TRIAL (4,7,15)	TRIAL (4,7,15)
Proofing Scrap	NORM(10,14)	NORM(10,14)
Washing & Rubbing Down Process	UNIFORM(8,12)	UNIFORM(8,12)
Painting Process	TRIAL(6,8,13)	TRIAL(4,8,10)
Final Fitting	CONSTANT(9)	CONSTANT(9)
Final Inspection Process	TRIAL (3,6,10)	TRIAL (3,6,10)
Transport to Warehouse	WEIB(5,8)	WEIB(5,8)

4.3 Proposed Method

Three types of waste motion, movement and waiting, (Acaccia et al, 1999; Lean Manufacturing Tools, 2016), were identified in the current layout. The welding station was recognised as the bottleneck station, causing a delay to fixture process because of the type of movement waste identified. Buffer storage was created in the welding station. The improved layout is shown as Appendix 1. The buffer storage was created to alleviate movement and the waiting period in the welding station.

5. Results and Discussion

5.1 Output Result

Reconstruction of facilities layout assisted in increasing average utilization of resource. Table 2 represents resource utilization for the current and proposed model.

Table 2: Average Utilization of Resources

Resource Utilization	Current Model	Proposed Model
	Average %	
Final Fitting Inspector	0.2254	0.2703
Fitter	0.33	0.395
Fork Lift	0.1402	0.1686
Fork Lift driver	0.1227	0.1052
Inspector	0.5001	0.6242
Jigger 1	0.3329	0.3592
Operator 1	0.247	0.2962
Painter	0.3339	0.3889
Proofing crew	0.4182	0.4782
Rework Assist	0.1895	0.2065
Washer (operator)	0.3683	0.4419
Welder 1	0.1318	0.1421
Welder 2	0.2798	0.2218

Table 3 presents the average waiting time for the current and proposed model. There is a minor reduction in average waiting time for the proposed simulation.

Table 3: Average waiting Times (Sec)

Average waiting Table (Sec)		
Process	Current Model	Proposed Model
Door Hanging	0.0011	0.0014
Final Fitting Process	0.0024	0.0025
Final Inspection Process	0.00001043	0
Fixture Process	0.0279	0.04
Inspection	0.1091	0.32
Painting Process	0.0021	0.0026
Proofing process	0.0291	0.0543
Proofing scrap	0.02771	0.0044
Rework Process	0.1046	0.1964
Transport to warehouse	0.0004	0
Washing and Rubbing Down	0.012	0.1906
Welding Station 1	0.0071	0.0066
Welding Station 2	0.0277	0.0187

Figure 9 display a graphical representation of the current and proposed model. The count model function was used capture proofing scrap products, record non confirming items, scrape rate (final line), store in warehouse and system output.

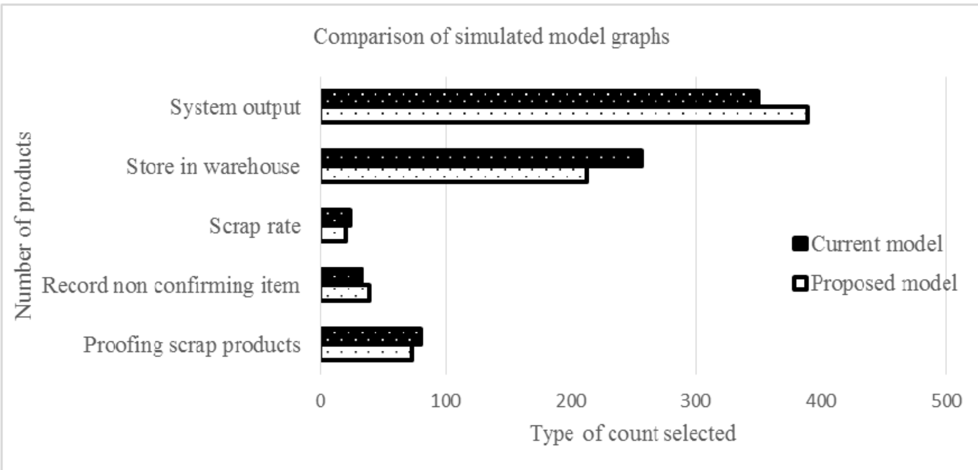

Figure 9, Comparison of simulated model graphs

6. Conclusion

The primary objective of this research was to make a comparison of one simulation model with two different scenarios. ARENA simulation software was used to create a simulation model. The research was based on optimising Safe production in South Africa. The base model system output was low due to waste of waiting, movement and motion due to improper layout design. These various forms of waste assisted in identifying the bottleneck station, which was the welding station. A buffer station was created next to the welding station to reduce movement and average waiting time. Simulation techniques and methods were used to create two simulation models. Assumptions and replication parameters where taken into consideration during simulation modelling of the two scenarios. After analysis, testing was conducted; there was an increase in output from the proposed improved model. The average resource utilization shown in Table 3 indicated an increase in both equipment and labour utilisation levels and there was reduction in the average waiting time. This agreed with the work of El-Khalil, (2013), who indicated that a buffer station improves scheduling, reduces work-in-process inventory and enhances use of resources. The study concludes that manufacturing system optimization can be achieved using ARENA simulation and facilities layout reconfiguration. The limitation of this paper is that it did not look at the buffer space cost and inventory holding costs.

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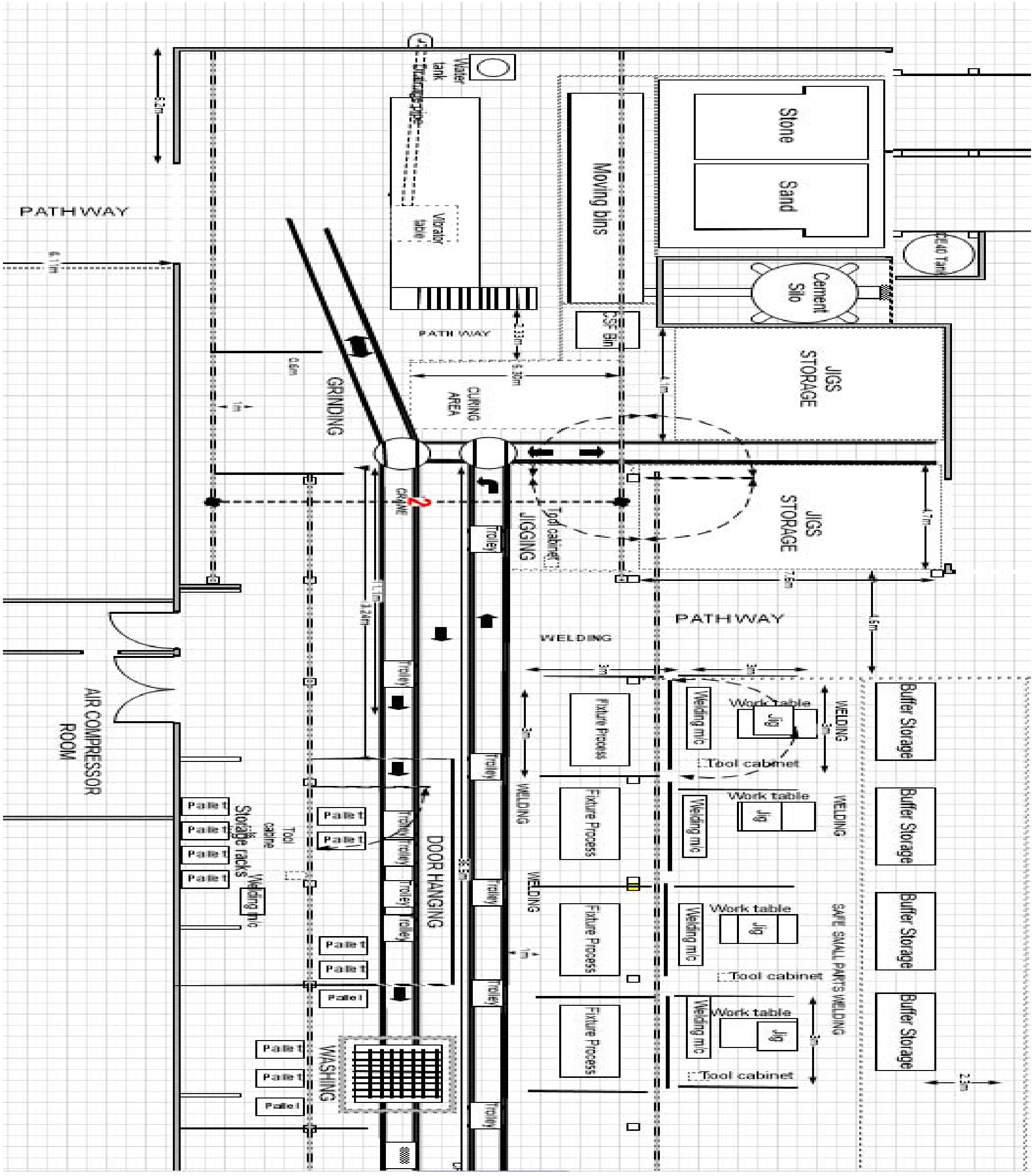
Appendix 1: Proposed Model

Improved Layout with a Buffer storage and welding station is brought parallel to fixture to avoid movement.



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